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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA-MSC-G-R-65-4
Supplemental Report 7 - Part II

NASA PROGRAM GEMINI WORKING PAPER NO. 5045

# UHF COMMUNICATIONS SPACECRAFT-TO-GROUND TESTS PERFORMED AT THE BERMUDA TRACKING STATION DURING GEMINI V MISSION

Issued as: Supplemental Report 7 - Part II

To : Gemini Program Mission Report - Gemini V MSC-G-R-65-4

By : Gemini V Mission Evaluation Team

[redacted]

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

April 12, 1966

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# UHF COMMUNICATIONS SPACECRAFT-TO-GROUND TESTS PERFORMED AT THE BERMUDA TRACKING STATION DURING GEMINI V MISSION

Prepared by


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By : Gemini V Mission Evaluation Team

AUTHORIZED FOR DISTRIBUTION

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
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# ABBREVIATIONS

| | |
|---|---|
| ADPTR | Adapter |
| ANT | Antenna |
| AOS | Acquisition of signal |
| BST | Brief system test |
| BW | Bandwidth |
| dB | Decibel |
| dBm | Decibels below 1 milliwatt |
| DST | Delayed-system test |
| DT | Delayed time |
| G/S | Ground-to-spacecraft |
| G.m.t. | Greenwich mean time |
| HF | High frequency |
| LCP | Left circular polarized |
| LOS | Loss of signal |
| Mc | Megacycle |
| μV | Microvolt |
| n. mi. | Nautical mile |
| P | Pitch |
| PCA | Point of closest approach |
| PCM | Pulse code modulated |
| PTT | Push-to-talk |
| R | Roll |
| RCP | Right circular polarized |
| rev. | Revolution |
| RNTRY | Reentry |
| RCVR | Receiver |
| RT | Real time |
| SC | Gemini spacecraft |
| S/G | Spacecraft-to-ground |
| S/N | Serial number |
| S/R | Slant range |
| TM | Telemetry |
| USAF | United States Air Force |
| UHF | Ultra high frequency |
| USN | United States Navy |
| Y | Yaw |

# 1.0 INTRODUCTION

A special test to evaluate the performance of the Gemini real-time telemetry and the UHF voice communications systems under operational conditions was requested by the Gemini Program Office, Manned Spacecraft Center during the Gemini V mission. To accomplish this objective four separate spacecraft-to-ground transmission tests were conducted at the Bermuda Tracking Station during the following revolutions of the above mission:

| Test no. | Revolution |
|---|---|
| 1 | 31 |
| 2 | 32 |
| 3 | 14 |
| 4 | 29 |

There was no special instrumentation installed to gather the data other than the ground station and spacecraft communication equipment normally used during an operational mission.

It is the purpose of this report to present an evaluation of system performance based on a detailed analysis of the signal strength measurements as recorded by the ground station and time correlate this with spacecraft attitude and empheris data obtained during the test.

# 2.0 UHF COMMUNICATION SYSTEMS

## 2.1 Bermuda Tracking Station Instrumentation

The voice communications and the telemetry used in the tests are dual systems, both utilizing the same 9-turn quadhelix antennas. These antennas are mounted on 40-foot towers separated by 182 feet to provide space diversity. The audio output of each UHF voice receiver is applied to the input of a Diversity Combiner (Bendix Model DDU-100) which gives a single output having a signal-to-noise ratio equal to or more than that of the optimum receiver.

The dual real-time (RT) and delayed-time (DT) telemetry receiving systems are simultaneously the same 9-turn quadhelix antenna arrays as are used for UHF voice. Also, the output of each receiver is applied to the input of a Diversity Combiner (Nems - Clark Mod. DCA-510). The RT data are transmitted continuously from the spacecraft during the station pass.

In the Gemini V mission, the data recorded on board the spacecraft was transmitted at high speed to the Cape Kennedy Tracking Station. However, the Bermuda Tracking Station received the last 60 to 90 seconds of these transmissions which started immediately after acquisition of signal (AOS). The performance status of the Bermuda HF and UHF voice-transmitting and receiving equipment was within specification limits, as determined by the delayed-system tests (DST) conducted 3 days prior to the scheduled launch date. The interval between completion of the delayed-system test and launch was devoted to clearing up minor defects in the system proper. Brief system tests conducted immediately before launch, and repeated daily during the Gemini V mission, did not reveal any degradation or changes in system performance. (The Bermuda Tracking Station instrumentation used in the tests, and the most significant characteristics of this system are presented in tables 2-I and 2-II, respectively.)

## 2.2 Gemini Spacecraft Instrumentation

Two identical transmitter/receivers are available for spacecraft-to-ground (S/G) and ground-to-spacecraft (G/S) voice communications. One is held as a standby in the event of failure of the other. Three telemetry transmitters send the instrumentation-processed data down to the ground. (See fig. 2-1.) The RT and DT transmitters in the spacecraft receive the pulse code modulated (PCM) data from the onboard programer and recorder, respectively. The third transmitter is held as standby in the event of a failure of either the RT or DT transmitter.

The UHF voice and RT telemetry transmitters transmit and, in the case of the UHF voice, receive (via a quadriplexer and a coaxial switch) through a quarter-wave stub (reentry) antenna located in the nose of the spacecraft or over a similar antenna located in the forward adapter section, as shown in figure 2-2.

The DT telemetry transmitter and the acquisition-aid beacon radiate via a Diplexer and the UHF whip antenna located in the rear-adapter section. After spacecraft separation from its booster, but before reentry, the choice of either the reentry antenna or of the antenna located in the forward adapter section is made by the pilot. Patterns for these antennas at the UHF voice frequency (296.8 Mc/sec), the RT telemetry frequency (230.4 Mc/sec), and at the DT telemetry frequency (246.3 Mc/sec) are shown in figures 2-3 through 2-7, inclusive. Frequent reference is made to these patterns throughout this report; therefore the coordinate system used on the spacecraft antenna patterns and the approximate location of the antennas involved are both depicted in figure 2-2.

## 2.3 Gemini Spacecraft Antenna Patterns

Examination of the patterns shown in figures 2-4 and 2-6 for the UHF voice and real-time telemetry frequencies, respectively, shows that the pattern for the adapter antenna is essentially a "donut" with +4 to +4.8 dB lobes approximately in the (horizontal) yaw plane, $\phi = 90°$ and $\phi = 270°$, and with a sharp -18 dB null area centered at $\phi = 170°$ and $\theta = 80°$, while on the opposite side of the spacecraft in the vicinity of $\phi = 320°$ and extending from $\theta = 20°$ to $\theta = 140°$, a much larger null area occurs (i.e., one of -18 dB). The patterns shown in figures 2-3 and 2-5 for the nose antenna present essentially an omnidirectional coverage varying from -3 to +3 dB over the entire spacecraft, except for comparatively small null areas of -6 to -15 dB in the vicinity of $\phi = 90°$ to $\phi = 160°$ and $\theta = 20°$, and a -6 dB null area near $\phi = 220°$ and $\theta = 10°$, as shown on the pattern for the UHF voice frequency. The reentry antenna pattern for the real-time telemetry shows that null areas "looking" in the direction of the +Z azis are much deeper, that is, -25 dB, and are centered on the opposite side of the spacecraft near $\theta = 30°$ and $\phi = 240°$.

TABLE 2-I.- BERMUDA TRACKING STATION INSTRUMENTATION, GEMINI V MISSION

| Quantity | Subsystem | Model no. | Remarks |
|---|---|---|---|
| 2 | Transmitters, Collins Type | T-217/GR | UHF voice 296.8 Mc/sec |
| 2 | Power Supplies & Mod., Collins Type | MD-129/GR | -- |
| 2 | Receivers, Collins Type | R-278 B/GR | UHF voice 296.8 Mc/sec |
| 1 | Diversity Combiner, Bendix | DDU-100 | 2.5 to 3.0 dB S/N improvement |
| 6 | Preamps, Nems-Clarke | PR-203[a] | 27 dB gain |
| 2 | 9-turn, Quadhelix, L. Circ. Pol. Antenna, UHF[b] | -- | 17 dB gain |
| 4 | Receivers, Nems-Clarke | 1455 | -- |
| 2 | Diversity Combiners, Nems-Clarke | DCA-510 | -- |

[a]Four preamplifiers are used in the telemetry links and two are used in the UHF voice receiving system. The 27 dB gain shown is at the voice frequency of 296.8 Mc/sec.

[b]This array is designed and used simultaneously for telemetry and UHF voice communications in the 225 and 300 Mc/sec bandwidth, a gain of approximately 18 dB.

TABLE 2-II.- BERMUDA TRACKING STATION - SYSTEM DATA

Height of antenna above sea level = 83 feet

Spacing of antenna towers = 182 feet

UHF line losses:

a. Preamp to No. 2 Antenna = 1.4 dB; to No. 1 Antenna = 1.4 dB

b. Preamp to No. 1 Receiver = 4 dB; to No. 2 Receiver = 2 dB

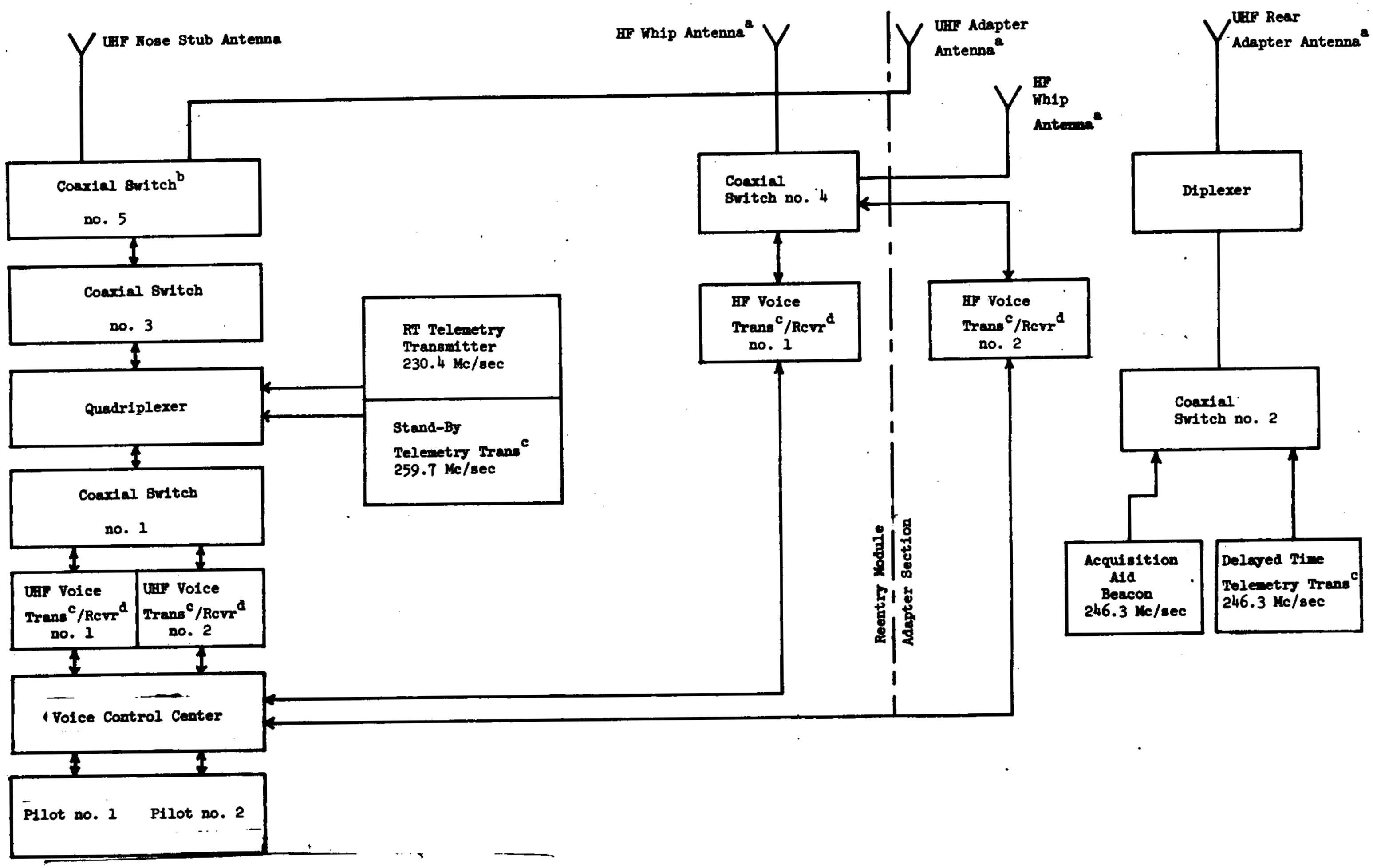
Receiver BW = More than 10 dB attenuation below 200 cps and above 5000 cps

UHF antenna BW = 18 degrees at 6 dB point

UHF transmitter power output = 160 W

Receiver sensitivity = 1.4 μV

Tracking accuracy = ±0.5 degree




[a]Antenna deployed at spacecraft separation from booster
[b]Controlled by antenna selector switch on control panel
[c]Transmitter
[d]Receiver

Figure 2-1.- Simplified block diagram of spacecraft communication system.

NASA-S-65-11667A

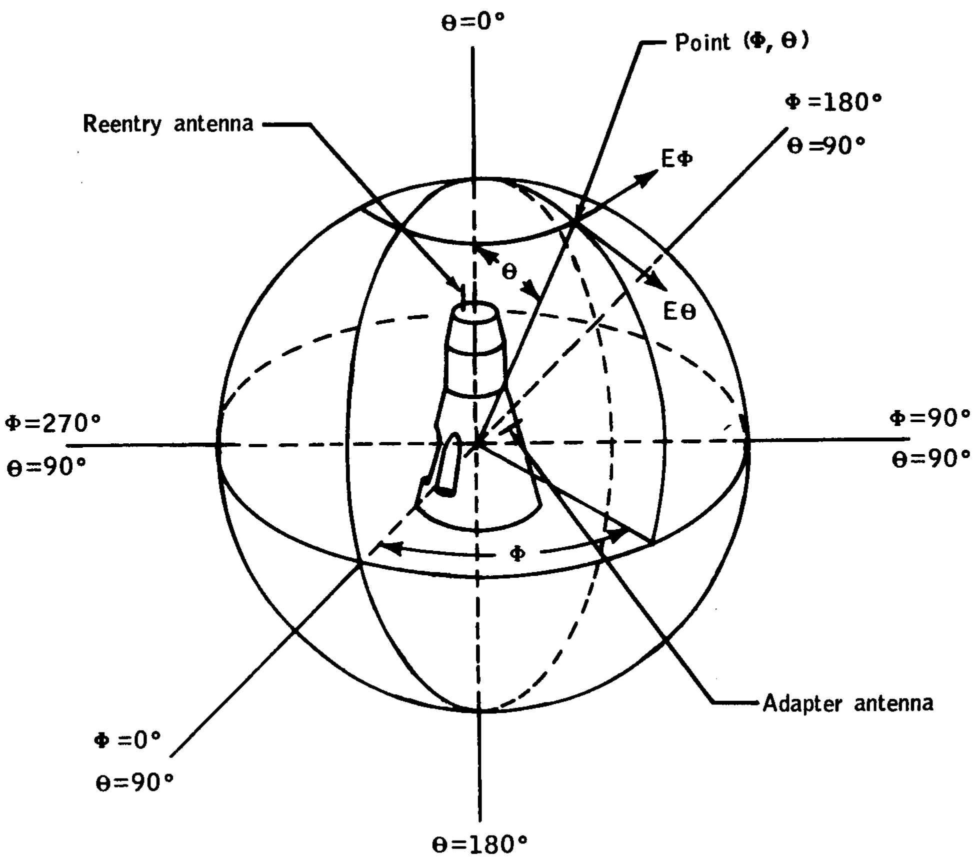



Figure 2-2.- Spacecraft antenna pattern, coordinate system.

NASA-S-65-11674A

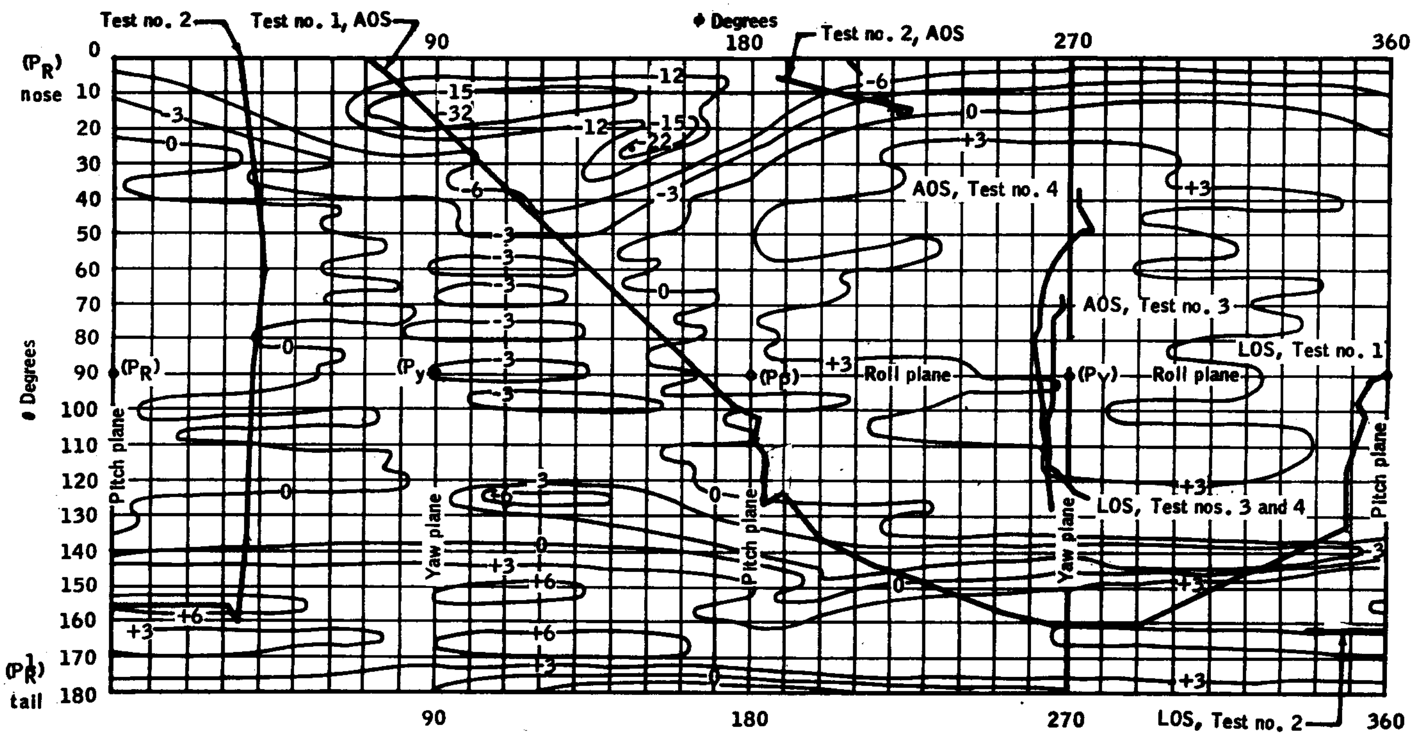



Figure 2-3.- UHF nose stub antenna pattern, UHF voice (freq. 296.8 Mc/sec).

NASA-S-65-11673A

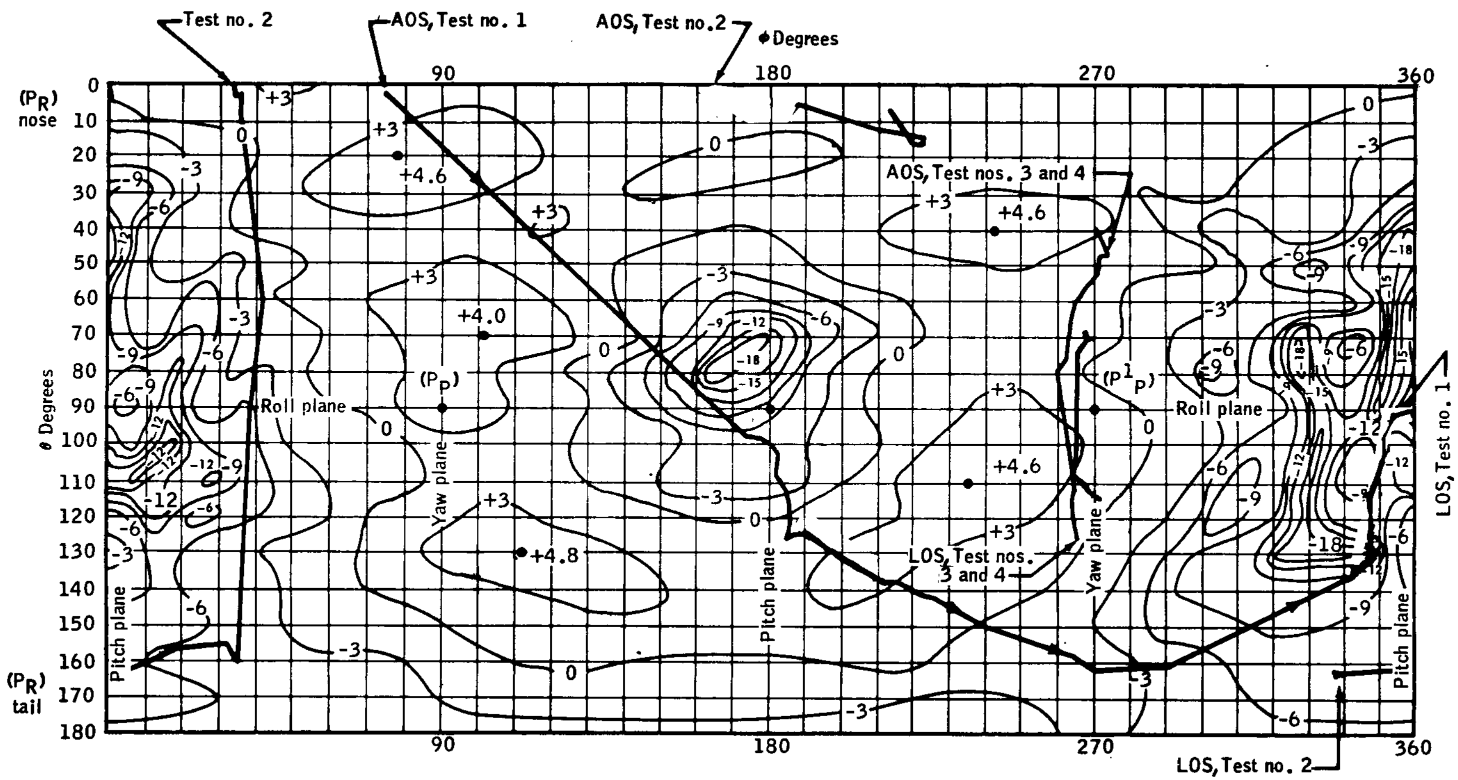



Figure 2-4. - UHF adapter antenna pattern, UHF voice (freq. 296.8 Mc/sec).

NASA-S-65-11675A

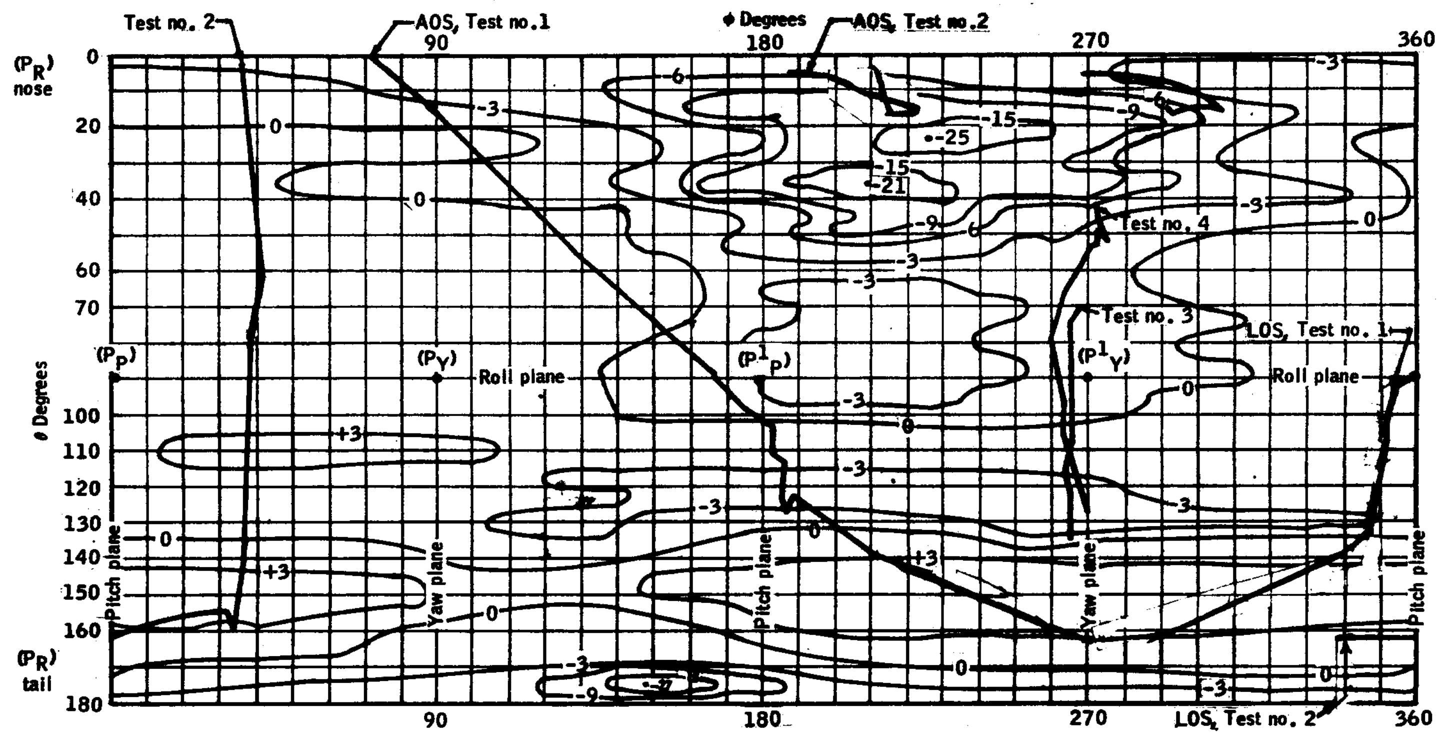



Figure 2-5.- UHF nose stub antenna pattern, RT telemetry (freq. 230.4 Mc/sec).

NASA-S-65-11677A

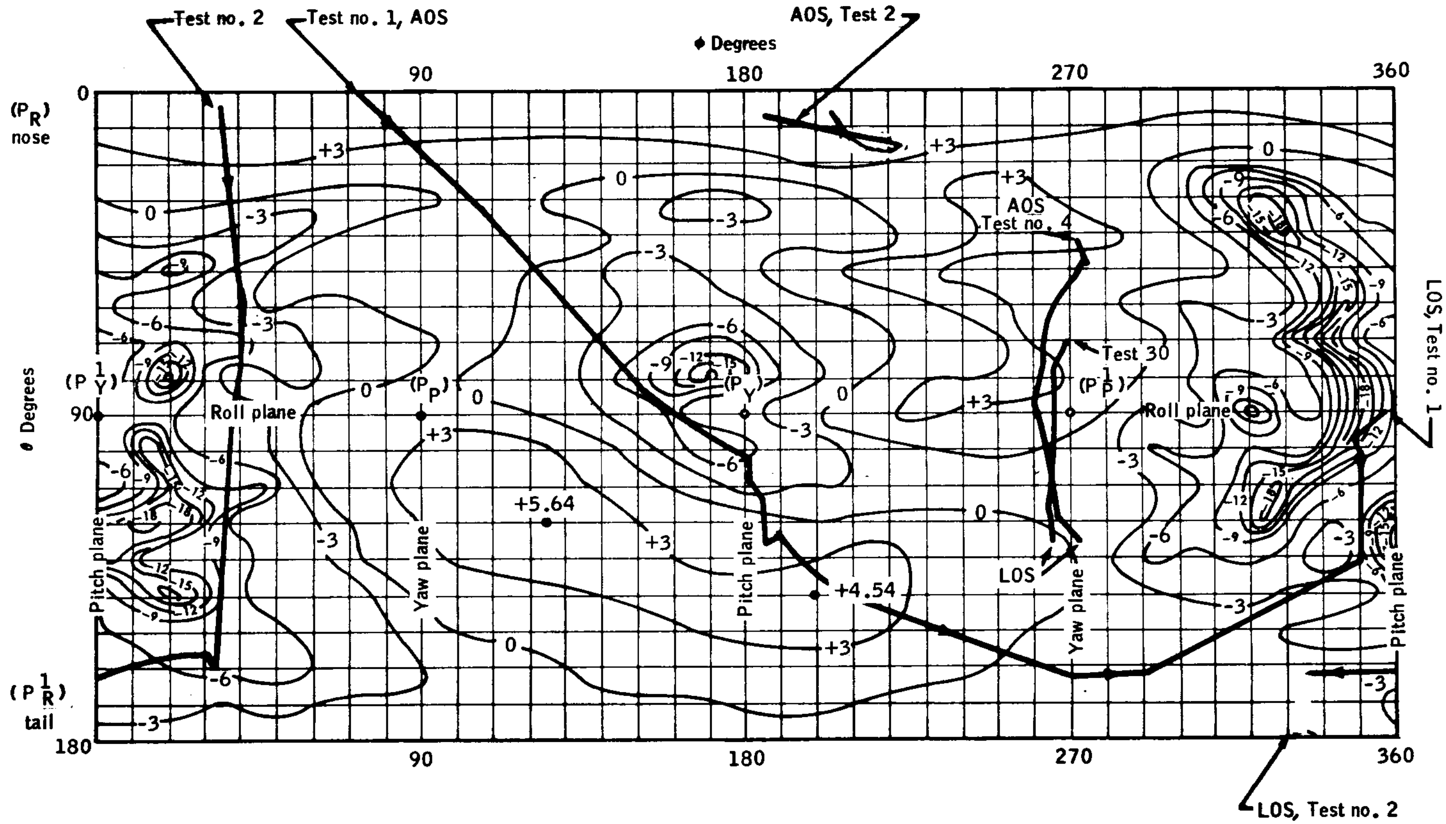



Figure 2-6.- UHF adapter antenna pattern, RT telemetry (freq. 230.4 Mc/sec).

NASA-S-65-11676A

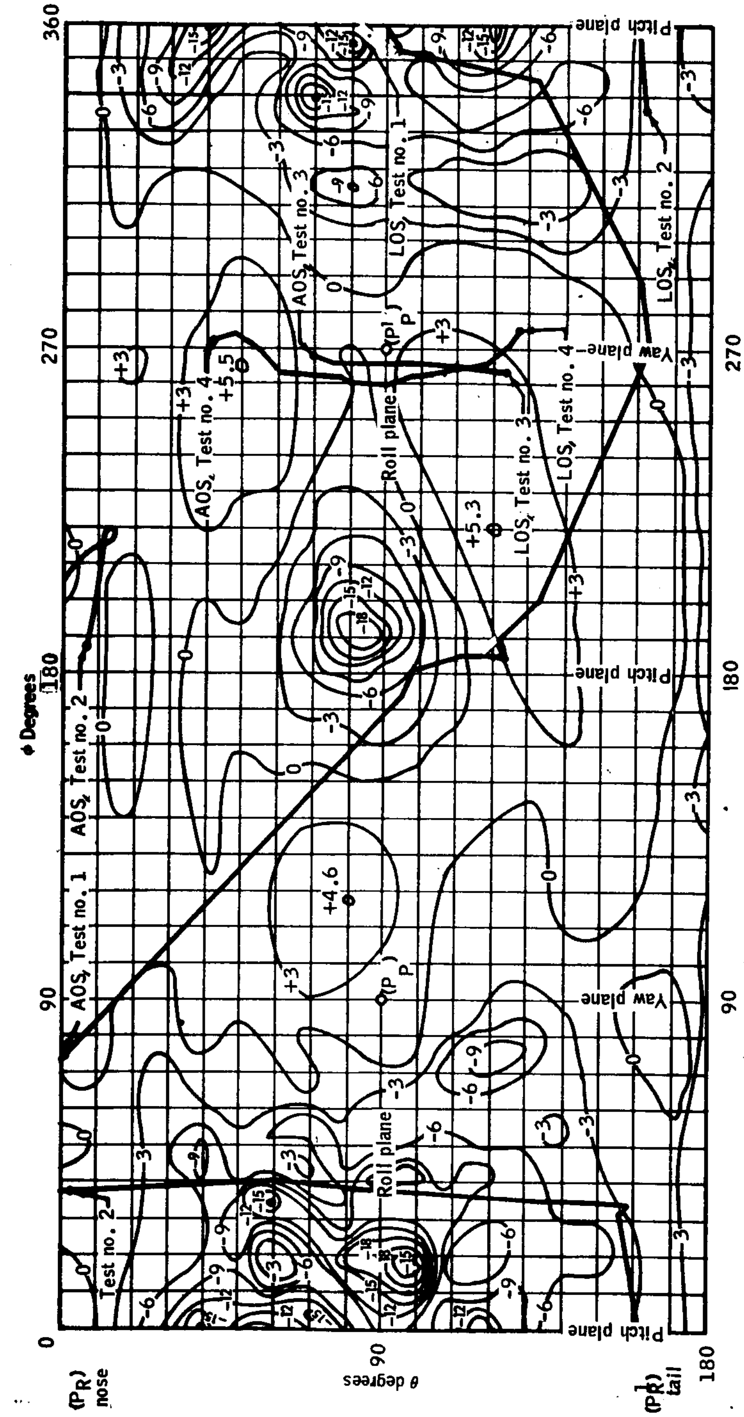



Figure 2-7.- UHF rear-adapter antenna, DT telemetry (freq. 246.3 Mc/sec).

# 3.0 TESTS CONDUCTED

## 3.1 Test No. 1, Revolution 31

3.1.1 Test procedures.- The pilot PTT (push-to-talk) keyed the UHF voice transmitter, continuously, from acquisition of signal (AOS) at Bermuda until loss of signal (LOS). He released the PTT key for 10 seconds each minute during his pass, permitting G/S transmission, if requested. Starting with the reentry antenna, the pilot switched alternately every 20 seconds from the reentry antenna to the adapter antenna and reported to the Bermuda Tracking Station. Also, during the entire pass, the pilot was to have maintained the following vehicle attitude:

Pitch = 90° up
Roll = 0° (See fig. 3-1)
Yaw = 14° left

3.1.2 Test results.- The results of this test are summarized in table 3-I, and additional data are presented in table 3-V. The test was not started until 1 minute and 30 seconds after AOS. Proper spacecraft attitude was not achieved until 34 seconds before it reached its point of closest approach (PCA). The trace showing that part of the spacecraft presented to the ground antenna is plotted in figures 2-3 through 2-6. These patterns indicate that the adapter antenna had a +18 dB advantage over the reentry antenna at AOS, and also at the start of the test. Conversely, the reentry antenna had a +3 to +15 dB advantage over the adapter antenna during the remainder of the pass. The antenna pattern may be briefly described by the following data:

| Phase of pass: | Adapter antenna | | Reentry antenna | |
|---|---|---|---|---|
| | UHF voice, dB | RT telemetry, dB | UHF voice, dB | RT telemetry, dB |
| At AOS | +3 | +3 | -15 | -4 |
| After AOS to PCA | -6 to +4 | -3 to 0 | -8 to +2 | -3 to +0 |
| After PCA to LOS | -15 to -5 | -15 to +1 | -15 to +1 | 0 to +3 |

The signal strength at input to the voice receiver varied from 15 μV at AOS, increased to 400 μV at PCA, and decreased to 5 μV at LOS. The real-time telemetry strength varied from -95 dBm at AOS to -80 dBm near PCA then decreased to -107 dBm at LOS (see fig. 3-5). This indicates adequate signal strength for both voice and telemetry.

## 3.2 Test No. 2, Revolution 32

3.2.1 Test procedures.- The procedures for this test were the same as those for test no. 1, except that the pilot was to have maintained the following vehicle attitude:

$$\begin{aligned} \text{Pitch} &= 0^\circ \\ \text{Roll} &= 132^\circ \quad \text{(See fig. 3-2)} \\ \text{Yaw} &= 0^\circ \end{aligned}$$

3.2.2 Test results.- The results of this test are summarized in table 3-II. The trace showing that part of the spacecraft presented to the ground receiving antenna, from AOS to LOS, is delineated in figures 2-3 through 2-6. These patterns indicate that during the initial phase of the pass the adapter antenna had an advantage over the reentry antenna on both the voice and telemetry frequencies of +17 and +18 dB, respectively. Conversely, the reentry antenna had an advantage of +5 to +18 dB over the adapter antenna from near PCA to LOS on both frequencies. This is explained by the fact that the spacecraft attitude during this period was such that the ground antenna was "looking" into the area $\phi = 35^\circ$ and $\theta$ varying from $0^\circ$ to $162^\circ$ which is on the edge of a large null area for the adapter antenna. The antenna patterns may be briefly described by the following data.

| Phase of pass: | Adapter antenna | | Reentry antenna | |
|---|---|---|---|---|
| | UHF voice, dB | RT telemetry, dB | UHF voice, dB | RT telemetry, dB |
| At AOS | -2 to +3 | +6 | -15 | -4 |
| After AOS to PCA | -6 to +4 | -3 to +2 | -8 to 0 | -3 to 0 |
| After PCA to LOS | -5 to -15 | -3 to -15 | 0 to +3 | 0 to +3 |

The voice signal strength varied from 15 to 200 μV. Readability was not good due to considerable background noise. This noise appeared to come from within the spacecraft. Signal strength of the real-time telemetry varied from -100 dBm to -80 dBm (2.4 to 23 μV), which is adequate for good telemetry data. This indicates that the telemetry does not have the same surplus circuit margin held by the voice frequency; furthermore, it indicates that the effects of lobing (namely, the interaction of the reflected ray with the direct ray at the receiving antennas) is a problem at the RT telemetry frequency. At low evaluation angles of the ground receiving antenna, lobing can result in nulls of +25 or more dB, as illustrated in figure 3-8.

This figure depicts the actual signals received during test no. 2, revolution 32, when the spacecraft was southeast of the station, at a slant range of 600 to 700 nautical miles and at an elevation angle of 2° to 3° for the ground antenna. Also, figure 3-8 shows where the signal into the pre-amp of the receiving channel 1A reached a null of -120 dBm (decibels below 1 milliwatt) within 1 second from coincidence with a -106 dBm null in receiving channel 1B. When this occurs there is usually a loss of telemetry lockon. The use of this dual reception system, its receiving antennas being separated by 182 feet, minimizes the possibility of null areas occurring simultaneously in both receiving channels. However, as indicated above, space diversity, at times, is not the most effective means for compensating for the difference in path length between direct and reflected rays.

## 3.3 Test No. 3, (Revolution 14) and Test No. 4, (Revolution 29)

3.3.1 Test procedures.- Test procedures for both of these passes were essentially the same, except that the adapter antenna was used in test no. 3, and the reentry antenna was used in test no. 4. Test procedures for both passes were: roll, pitch, and yaw were held at 0°; the pilot PTT keyed the transmitter continuously from the Bermuda Tracking Station AOS to LOS. During this time, the pilot would release the PTT key for 10 seconds during each minute of the pass.

3.3.2 Test results.- The results of these two tests are presented in tables 3-III and 3-IV. However, the highlights of the tests are further summarized in the following table:

| Spacecraft antenna used: | Test no. 3 | Test no. 4 |
|---|---|---|
| | Adapter | Reentry |
| Elevation of ground antenna from AOS to LOS | -.9° to +1.9° | -.2° to +5.2° |
| Slant range at AOS | 750 n. mi. | 874 n. mi. |
| Slant range at PCA | 722 n. mi. | 582 n. mi. |
| Slant range at LOS | 874 n. mi. | 701 n. mi. |
| SC antenna pattern presented to ground, voice frequency | +1 to +4 dB | 0 to -5 dB |
| SC antenna pattern, RT telemetry frequency | -1 to +3 dB | -1 to -3 dB |
| Signal strength at ground voice receivers | 30 to 50 μV | 25 to 40 μV |
| Signal strength at ground TM receivers | -90 to -95 dBm | -90 to -104 dBm |
| SC antenna pattern, voice frequency | +1 to +3 dB | +2 to +3 dB |
| Telemetry reception | Good | Fair to good |
| Readability of voice reception | Excellent | Fair |

Figures 3-3 and 3-4 are plots of the signal strength at input of ground receiver no. 2 and shown as a function of slant range for test nos. 3 and 4, respectively. The scale of each plot is adjusted to include the slant range encompassing spacecraft travel from AOS to LOS. A small plot in the upper left hand corner of each chart shows the approximate slant range from the spacecraft to the ground antenna and the azimuth angle for each pass. Due to the very low elevation angle (a max. of 1.9° for test no. 3, and of 5.2° for test no. 4) of the ground antenna, considerable lobing resulted, such as occurred in test no. 2. However, lobing was never sufficient to cause fading of the UHF voice. An examination of the Bermuda real-time telemetry signal strength during these passes indicates that lobing at the frequency 230.4 Mc/sec was sufficient to cause loss of signal.

Signal strength on the voice frequency dropped to zero during the short interval when the spacecraft was approximately 785 nautical miles south of the station during test no. 4, revolution 29 (see fig. 3-4). An expanded view (an approximately 22-second interval) of the signal during this time period is shown in figure 3-6. From figure 3-6 it can be seen that the signal either dropped to zero or oscillated violently at frequencies of 5 to 10 cps in both receiving channels (i.e., nos. 1 and 2). The effect of the RT telemetry (230.4 Mc/sec) and the DT telemetry (246.3 Mc/sec) is shown in figure 3-7. This disturbance resulted in fadeout of the UHF S/G voice and complete dropout of the RT and DT telemetry on both receiving channels during a period of approximately 20 seconds.

During this interference, slant range was approximately 785 nautical miles south of the station; the elevation angle of the ground receiving antennas was 1.5°. However, the station is located less than $\frac{1}{2}$ mile southwest of Kindley AFB runway: therefore, this interference was presumably due to reflections from low-flying aircraft in the immediate vicinity of the ground receiving antenna. Large USAF and USN transports as well as several commercial jet aircraft use this runway.

As previously pointed out, test nos. 3 and 4 were fringe passes south of the tracking station; consequently, the left side of the spacecraft ($\phi$ = 270, and $\theta$ varying from 40° to 125°) was presented to the ground antennas. The patterns at the voice frequency (figs. 2-3 and 2-4) indicate that, during both passes, the ground antenna predominately "looked" into the +3 dB lobe for either the adapter or the reentry antenna. Whereas, at the RT telemetry frequency, the antenna pattern presented to the ground station varied from -1 to +3 dB for the adapter antenna, and from -1 to -9 dB for the reentry antenna (i.e., when the reentry antenna is in use). If these had been fringe-area passes to the north of the ground tracking station, the right side ($\phi$ = 90°) of the spacecraft would have been presented to the ground antenna.

An examination of the pattern under these circumstances indicates that the adapter antenna would have had an advantage for the voice frequency, which varied from +4 to +15 dB over the reentry antenna. Whereas, at the RT telemetry frequency, the pattern presented for both the adapter and the reentry antenna would have varied from only 0 to +3 dB, and so have been practically the same for both antennas.

The above discussion concerning the advantage of one antenna over the other for fringe-area passes and low elevation angles (6° or less) of the ground receiving antenna is summarized below:

(a) For passes south of the station (the spacecraft attitude being held to within ±5° in roll, pitch, and yaw) the adapter antenna has an advantage of +1 to +6 dB over the reentry antenna, but it does not have an advantage over the reentry antenna at the UHF voice frequency.

(b) For passes north of the station, the spacecraft attitude being the same as that in paragraph (a) above, the adapter antenna has an advantage of +2 to +4 dB over the reentry antenna at the RT telemetry frequency, and an advantage of +3 to +20 dB over the reentry antenna on the UHF voice frequency.

From the results as summarized in paragraphs (a) and (b) above, it is concluded that in a normal orbital attitude (R, P, and Y = 0° ± 5°) the adapter antenna is optimum for both north and south fringe-area passes. This is significant, because most passes in multiorbit missions (e.g., as in Gemini V) are fringe passes. This applies to all tracking stations.

TABLE 3-I.- SUMMARY OF TEST RESULTS, UHF S/G TEST NO. 1,

REVOLUTION 31, GEMINI V MISSION, BERMUDA TRACKING STATION

| G.m.t., hr:min:sec | Position of spacecraft | | | Spacecraft attitude | | | "Look" angle of ground antenna (a) | | Spacecraft antenna gain | | Signal strength at ground rcvr[b] | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | UHF voice | | TM rcvr[b] (230.4 Mc/sec) | |
| | | | | | | | | | | | Spacecraft antenna | | Spacecraft antenna | |
| | Slant range, n. mi. | Elevation, deg | Azimuth, deg | Pitch angle, deg | Roll angle, deg | Yaw angle, deg | θ, deg | ϕ, deg | Adaptr[c], dB | Rntry[d], dB | Adapter[c], μV | Rntry[d], μV | Adptr[c], dBm | Rntry[d], dBm |
| 13:47:10 | 823 | -0.3 | -91 | 180 | 163 | 178 | 1 | 73 | + 3 | -15 | [e]15 | | | -105 |
| 48:27 | 518 | +6.0 | -89 | 205 | 176 | 174 | 26 | 100 | + 4 | - 8 | | 10 | - 90 | -103 |
| 48:48 | 448 | 8.2 | -89 | 231 | 176 | 177 | 98 | 174 | - 6 | - 1 | 36 | | - 90 | - 98 |
| 49:04 | 378 | 11.0 | -88 | 254 | 176 | 181 | 98 | 175 | - 6 | - 2 | | 30 | - 89 | - 96 |
| 49:10 | 355 | 12.4 | -88 | 270 | 176 | 181 | 103 | 182 | - 5 | 0 | 26 | 35 | | |
| 49:30 | 280 | 17.0 | -87 | 274 | 177 | 182 | 109 | 181 | - 4 | 0 | 40 | 40 | - 96 | - 89 |
| 49:36 | 257 | 18.9 | -86 | 276 | 177 | 186 | 113 | 185 | - 3 | 0 | 80 | | - 98 | - 87 |
| 49:39 | 243 | 28.3 | -86 | 277 | 177 | 188 | 125 | 186 | + 1 | 0 | 80 | | - 98 | - 86 |
| 50:02 | 166 | 32.4 | -82 | 271 | 181 | 195 | 123 | 189 | + 3 | 0 | 60 | | - 86 | - 82 |
| 50:18 | 119 | 49.6 | -74 | 267 | 183 | 199 | 137 | 200 | + 4 | - 3 | | 200 | - 78 | - 80 |
| [f]50:36 | 94 | 75.7 | - 4 | 266 | 184 | 199 | 162 | 270 | - 3 | + 3 | | 400 | - 80 | - 80 |
| 50:38 | 95 | 75.2 | +15 | 266 | 183 | 198 | 161 | 290 | - 5 | + 3 | | 400 | - 80 | - 77 |
| 50:58 | 128 | 49.9 | +73 | 266 | 183 | 193 | 136 | 343 | -12 | 0 | 80 | | - 84 | - 80 |
| 51:08 | 157 | 34.4 | +78 | 267 | 182 | 193 | 132 | 348 | -15 | 0 | 50 | 100 | - 86 | - 82 |
| 51:25 | 219 | 23.0 | +82 | 270 | 182 | 192 | 113 | 350 | -12 | + 2 | 60 | 50 | - 92 | - 84 |
| 52:06 | 369 | 11.4 | +85 | 270 | 178 | 188 | 102 | 353 | -15 | + 2 | 40 | 30 | -104 | - 90 |
| 52:27 | 453 | 8.0 | +86 | 271 | 174 | 188 | 98 | 350 | -15 | + 2 | 29 | 35 | -107 | - 93 |
| 53:10 | 617 | 3.5 | +87 | 268 | 177 | 190 | 92 | 354 | - 9 | 0 | 19 | 9 | -106 | - 95 |
| 53:28 | 688 | 2.0 | +87 | 266 | 180 | 190 | 90 | 357 | - 9 | 0 | 13 | 5 | -104 | - 97 |

[a]The range and angular data of the ground antenna together with the roll, pitch, and yaw angles of the spacecraft were used to obtain the "look" angles of the ground antenna relative to the spacecraft antenna pattern, coordinate system (ϕ and θ).

[b]Receiver.

[c]Adapter antenna.

[d]Reentry antenna.

[e]This transmission from the spacecraft was received on the ground 1 min 17 sec prior to start of test.

[f]Point of closest approach.

TABLE 3-II.- SUMMARY OF TEST RESULTS, UHF S/G TEST NO. 2,

REVOLUTION 32, GEMINI V MISSION, BERMUDA TRACKING STATION

| G.m.t., hr:min:sec | Position of spacecraft relative to Bermuda station | | | Spacecraft attitude | | | "Look" angle of antenna relative to spacecraft coordinates (a) | | Spacecraft antenna pattern corresponding | | Signal level at ground rcvr[b] | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | UHF voice spacecraft antenna system | | TM rcvr[b] (230.4 Mc/sec) spacecraft antenna system | |
| | Slant range, n. mi. | Elevation angle, deg | Azimuth angle, deg | Pitch angle, deg | Roll angle, deg | Yaw angle, deg | θ, deg | ϕ, deg | Adptr[c], dB | Rntry[d], dB | Adptr[c], µV | Rntry[d], µV | Adptr[c], dBm | Rntry[d], dBm |
| 15:22:05 | 660 | 2.5 | - 86 | 187 | 88 | 182 | 6 | 188 | - 2 | - 9 | 30 | | -98 | -100 |
| 22:24 | 525 | 4.1 | - 86 | 187 | 56 | 188 | 12 | 210 | + 1 | - 3 | 40 | | -94 | - 97 |
| 22:45 | 505 | 6.3 | - 88 | 186 | 47 | 193 | 15 | 223 | + 1 | - 1 | 35 | 40 | -92 | - 96 |
| 23:08 | 421 | 9.2 | - 90 | 184 | 51 | 196 | 16 | 220 | + 1 | 0 | | 40 | -87 | - 92 |
| 23:25 | 354 | 12.2 | - 92 | 182 | 56 | 198 | 16 | 214 | 0 | - 4 | | 40 | -90 | - 85 |
| 23:42 | 295 | 15.8 | - 95 | 181 | 57 | 195 | 10 | 213 | - 1 | - 6 | 50 | | -84 | - 83 |
| 24:08 | 205 | 25.1 | -104 | 182 | 54 | 191 | 3 | 36 | + 2 | -10 | 50 | | -83 | - 82 |
| 24:24 | 160 | 34.3 | -117 | 184 | 54 | 188 | 8 | 36 | + 1 | - 8 | 200 | 60 | -80 | - 81 |
| 24:43 | 126 | 47.0 | -153 | 182 | 49 | 183 | 60 | 41 | - 2 | + 1 | 80 | 200 | -86 | - 80 |
| [e]24:52 | 124 | 47.9 | -175 | 185 | 51 | 179 | 87 | 39 | - 6 | 0 | 60 | | -80 | - 78 |
| 25:25 | 190 | 27.9 | +131 | 189 | 56 | 175 | 136 | 37 | - 4 | 0 | 80 | 60 | -86 | - 80 |
| 26:00 | 306 | 15.4 | +118 | 187 | 56 | 177 | 160 | 34 | - 4 | + 6 | 45 | 30 | -84 | - 89 |
| 26:09 | 342 | 13.2 | +116 | 185 | 56 | 177 | 156 | 32 | - 5 | + 6 | 20 | 40 | -97 | - 90 |
| 26:44 | 479 | 7.5 | +112 | 186 | 56 | 178 | 156 | 30 | - 6 | + 6 | 15 | 34 | -90 | - 94 |
| 27:15 | 594 | 4.4 | +110 | 185 | 73 | 186 | 158 | 17 | - 6 | + 6 | | 30 | | - 97 |
| 27:45 | 703 | 2.1 | +109 | 189 | 113 | 191 | 162 | 337 | - 8 | + 3 | | 15 | | -102 |

[a]The range and angular data of the ground antenna together with the **roll, pitch, and yaw** angles of the spacecraft were used to obtain the "look" angles of the ground antenna relative to the spacecraft antenna pattern, coordinate system (ϕ and θ).

[b]Receiver.

[c]Adapter antenna.

[d]Reentry antenna.

[e]Point of closest approach.

TABLE 3-III.- SUMMARY OF TEST RESULTS, UHF S/G TEST NO. 3,

REVOLUTION 14, GEMINI V MISSION, BERMUDA TRACKING STATION

| G.m.t., hr:min:sec | Spacecraft position relative to ground antenna | | | Spacecraft attitude (a) | | "Look" angle of ground antenna (b) | | Spacecraft antenna pattern (c) | | | | Signal level at input to ground receivers | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Adapter antenna | | Reentry antenna | | | | |
| | Slant range, n. mi. | Elevation angle, deg | Azimuth angle, deg | Pitch angle, deg | Roll angle, deg | $\phi$, deg | $\theta$, deg | Voice (296.8 Mc)dB | RT TM (230.4 Mc)dB | Voice (296.8 Mc)dB | RT TM (230.4 Mc)dB | Voice rcvr[e] no. 2, μV | RT TM rcvr[e] (230.4 Mc/sec) | DT TM rcvr[e] (246.3 Mc/sec) (d) |
| 10:50:28 | 750 | 1.6 | 169 | 0 | 0 | 268 | 70 | +1 | +3 | +3 | -2 | 20 | | |
| [f]50:34 | 743 | 1.7 | 167 | -2 | +2 | 266 | 74 | +1 | +3 | +3 | -2 | 24 | | |
| 51:52 | 722 | 1.9 | 143 | -2 | +2 | 266 | 98 | +1 | 0 | +3 | -1 | 24 | | |
| 52:02 | 728 | 1.7 | 139 | -3 | +3 | 265 | 103 | +3 | 0 | +3 | 0 | 31 | -90 dBm max. | -95 dBm min.[g] |
| 52:32 | 760 | 1.1 | 131 | -4 | +4 | 265 | 110 | +3 | -1 | +3 | -2 | 18 | | |
| 52:44 | 778 | .8 | 127 | -5 | +4 | 265 | 113 | +3 | -1 | +3 | -3 | 30 | | |
| 52:50 | 787 | .6 | 126 | -5 | +5 | 264 | 115 | +3 | -1 | +3 | -3 | 44 | | |
| 53:14 | 831 | -.2 | 120 | -6 | +5 | 265 | 121 | +2 | 0 | +3 | -3 | 55 | | |
| 53:20 | 844 | -.4 | 118 | -6 | +5 | 265 | 124 | +1 | 0 | +2 | -3 | 65 | | |
| 53:34 | 874 | -.9 | 115 | -7 | +5 | 266 | 125 | 0 | 0 | +1 | -2 | 12 | | |

[a]Yaw was held at 0° throughout test.

[b]The slant range and angular tracking of the ground radar was used in conjunction with the attitude data of the spacecraft to obtain the "look" angles ($\phi$ and $\theta$) in terms of the Gemini spacecraft antenna pattern, coordinate system.

[c]The spacecraft adapter antenna was used on this test. However, the gain of reentry antenna is entered to permit comparison of both antennas for this pass.

[d]Delayed-time telemetry was on for 53 seconds prior to start of UHF voice tests.

[e]Receiver.

[f]Point of closest approach.

[g]Signal strength recording for RT Telemetry could not be located.

TABLE 3-IV.- SUMMARY OF TEST RESULTS, UHF S/G TEST NO. 4,

REVOLUTION 29, GEMINI V MISSION, BERMUDA TRACKING STATION

| G.m.t., hr:min:sec | Spacecraft position relative to ground antenna | | | Spacecraft attitude (a) | | "Look" angle of ground antenna (b) | | Spacecraft antenna patterns (c) | | | | Signal level at input to ground receivers | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Adapter antenna | | Reentry antenna | | | |
| | Slant range, n. mi. | Elevation angle, deg | Azimuth angle, deg | Roll angle, $\phi$, deg | Pitch angle, $\theta$, deg | $\phi$, deg | $\theta$, deg | Voice, 296.8 Mc | RT TM, 230.4 Mc | Voice, 296.8 Mc | RT TM, 230.4 Mc | Voice rcvr[d] no. 2, µV | RT TM receiver (230.4 Mc/sec) dBm |
| 10:39:43 | 874 | - .2 | -157.3 | -2 | -10 | 272 | 42 | +3 | +3 | +3 | -9 | 5 | -104 |
| 40:14 | 784 | +1.3 | -163.5 | -5 | - 8 | 274 | 48 | +2 | +3 | +3 | -6 | 8 | -102 |
| 40:16 | 778 | +1.4 | -164.0 | -5 | - 8 | 274 | 48 | +2 | +3 | +3 | -3 | [d]0 | [e]0 |
| 40:20 | 768 | 1.6 | -164.8 | -5 | - 7 | 273 | 48 | +2 | +3 | +3 | -3 | 30 | -100 |
| 40:34 | 733 | 2.2 | -168.1 | -3 | - 5 | 271 | 52 | +2 | +2 | +3 | -2 | 10 | - |
| 40:46 | 705 | 2.8 | -171.2 | -2 | - 4 | 269 | 55 | +2 | +1 | +3 | -2 | 30 | - |
| 41:07 | 659 | 3.7 | -177.5 | 0 | - 2 | 266 | 60 | +2 | +2 | +3 | -2 | 15 | - |
| 41:28 | 626 | 4.4 | +176.1 | +3 | 0 | 263 | 66 | +1 | +3 | +3 | -2 | 40 | - 96 |
| 41:46 | 602 | 4.9 | +169.7 | +3 | 0 | 262 | 75 | +1 | +3 | +3 | -2 | 25 | - |
| 41:58 | 591 | 5.2 | +165.2 | +5 | - 3 | 260 | 79 | +1 | +3 | +3 | -3 | 30 | - 90 |
| 42:47 | 584 | 5.2 | +145.4 | +2 | - 7 | 263 | 98 | +3 | 0 | +3 | -3 | 20 | - |
| 43:00 | 593 | 4.9 | +140.8 | +2 | - 8 | 263 | 104 | +3 | -1 | +3 | -1 | 14 | - 96 |
| 43:45 | 656 | 3.3 | +124.8 | +1 | - 8 | 266 | 118 | +2 | 0 | +2 | 0 | 16 | - |
| 43:58 | 679 | 2.8 | +121.2 | -2 | - 9 | 269 | 122 | +1 | 0 | +2 | -3 | 30 | - |
| 44:04 | 701 | 2.3 | +118.5 | -4 | -11 | 272 | 125 | 0 | -1 | +2 | -4 | 20 | - 93 |

[a] Yaw was to be held at 0° during test.

[b] Slant range and angular data of the ground antenna was used in conjunction with the spacecraft attitude data to obtain the "look" angles ($\phi$ and $\theta$).

[c] Spacecraft reentry antenna was used in this test. However, the pattern for the adapter antenna is shown to permit comparison of these two antennas for low elevation angles of the ground antenna.

[d] Receiver.

[e] See Section 4.0, par. 5 for explanation of loss of signal (on both voice and telemetry frequencies).

TABLE 3-V.- AVERAGE SIGNAL STRENGTH AT RT TELEMETRY FREQUENCY, RECEIVERS 1A AND 1B,

UHF S/G TEST NO. 1, REVOLUTION 31, GEMINI V MISSION, BERMUDA TRACKING STATION

| G.m.t., hr:min:sec | Spacecraft attitude | | | "Look" angles | | Spacecraft gain of antenna pattern | | RT TM average signal strength at input to rcvrs[a] 1B and 1A (b) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Roll angle, deg | Pitch angle, deg | Yaw angle, deg | $\phi$, deg | $\theta$, deg | Reentry, dB | Adapter, dB | Reentry, dB | Adapter, dB | R/A, dB (c) |
| 13:48:26 | 176 | 207 | 174 | 175 | 31 | -9 | - 3 | 102 | | |
| 48:43 | 176 | 225 | 176 | 175 | 59 | -3 | - 3 | 97 | 95 | - 2 |
| 49:03 | 176 | 250 | 180 | 174 | 85 | -3 | - 6 | 95 | 100 | + 5 |
| 49:25 | 178 | 270 | 180 | 174 | 102 | -1 | - 3 | 90 | 96 | + 6 |
| 49:45 | 179 | 277 | 189 | 180 | 111 | 0 | - 2 | 83 | 95 | +13 |
| 50:04 | 181 | 270 | 196 | 181 | 115 | -1 | - 2 | 82 | 86 | + 4 |
| 50:22 | 182 | 266 | 198 | 181 | 125 | -3 | 0 | 81 | 76 | - 5 |
| 50:43 | 182 | 266 | 195 | 197 | 123 | -1 | - 2 | 75 | 79 | + 4 |
| 51:04 | 182 | 266 | 194 | 270 | 147 | +1 | - 6 | 79 | 89 | +11 |
| 51:22 | 180 | 269 | 193 | 288 | 162 | +3 | - 6 | 88 | 90 | + 2 |
| 51:44 | 178 | 270 | 190 | 346 | 161 | +3 | - 7 | 89 | 93 | + 4 |
| 52:03 | 177 | 270 | 188 | 350 | 127 | +3 | - 8 | 90 | 98 | + 8 |
| 52:23 | 174 | 270 | 188 | 4 | 113 | +1 | -12 | 92 | 101 | +13 |
| 52:44 | 178 | 270 | 189 | 353 | 101 | 0 | -15 | 94 | 103 | + 9 |
| 53:07 | 180 | 269 | 190 | 352 | 97 | 0 | -12 | 95 | 104 | + 9 |
| 53:25 | 181 | 266 | 190 | 354 | 92 | 0 | -12 | 96 | 104 | + 8 |
| 53:44 | 182 | 266 | 193 | 357 | 88 | 0 | - 9 | 96 | 106 | + 8 |

[a]Receivers.

[b]This tabulation was included as an aid to prove which antenna was the optimum for the attitude of the spacecraft during this test.

[c]This column represents the improvement of the reentry antenna over the adapter for the attitude of the spacecraft during this test.

NASA-S-65-11664A

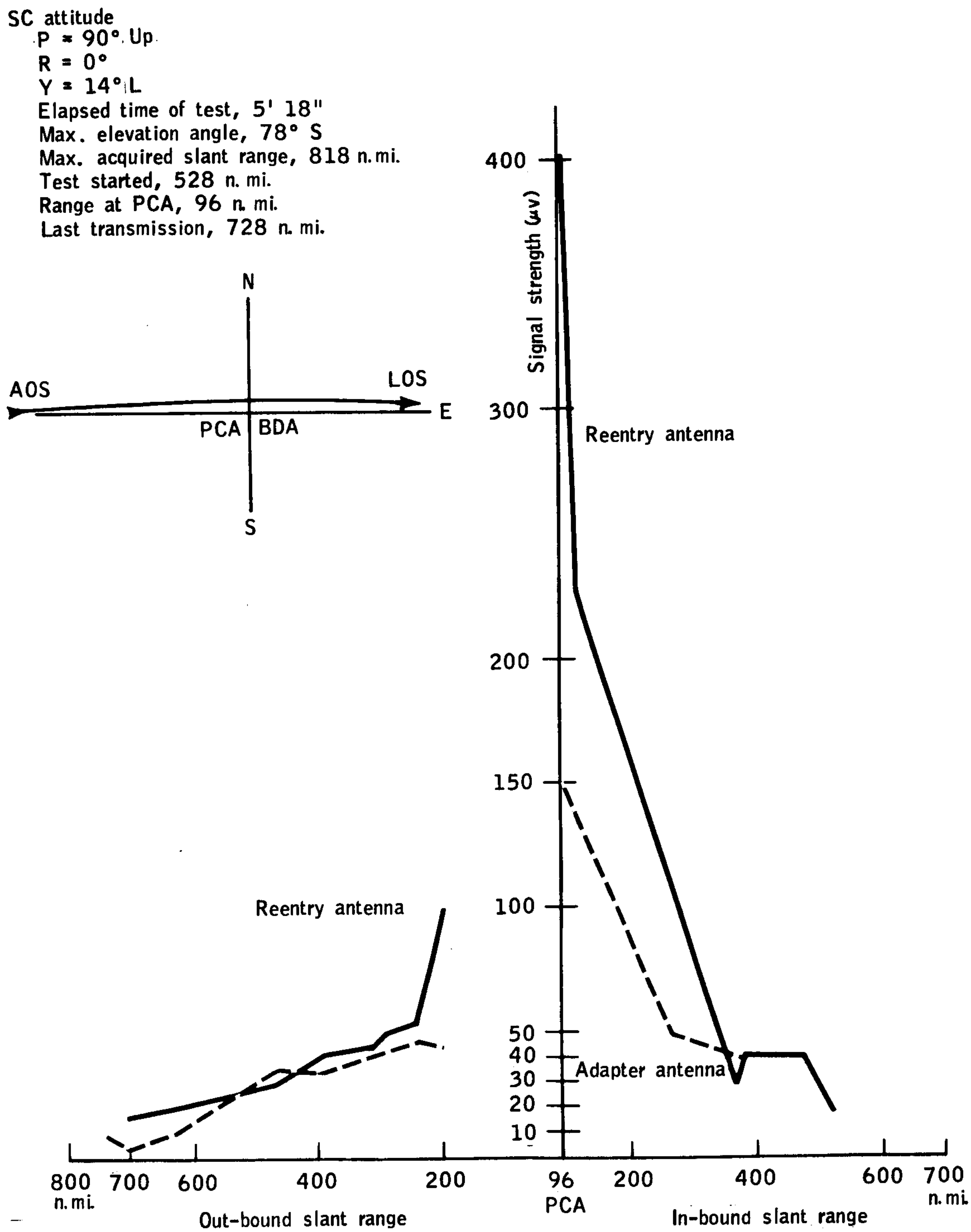



Figure 3-1.- Slant range versus S/G signal strength, UHF voice test no. 1, rev. 31.

NASA-S-65-11671A

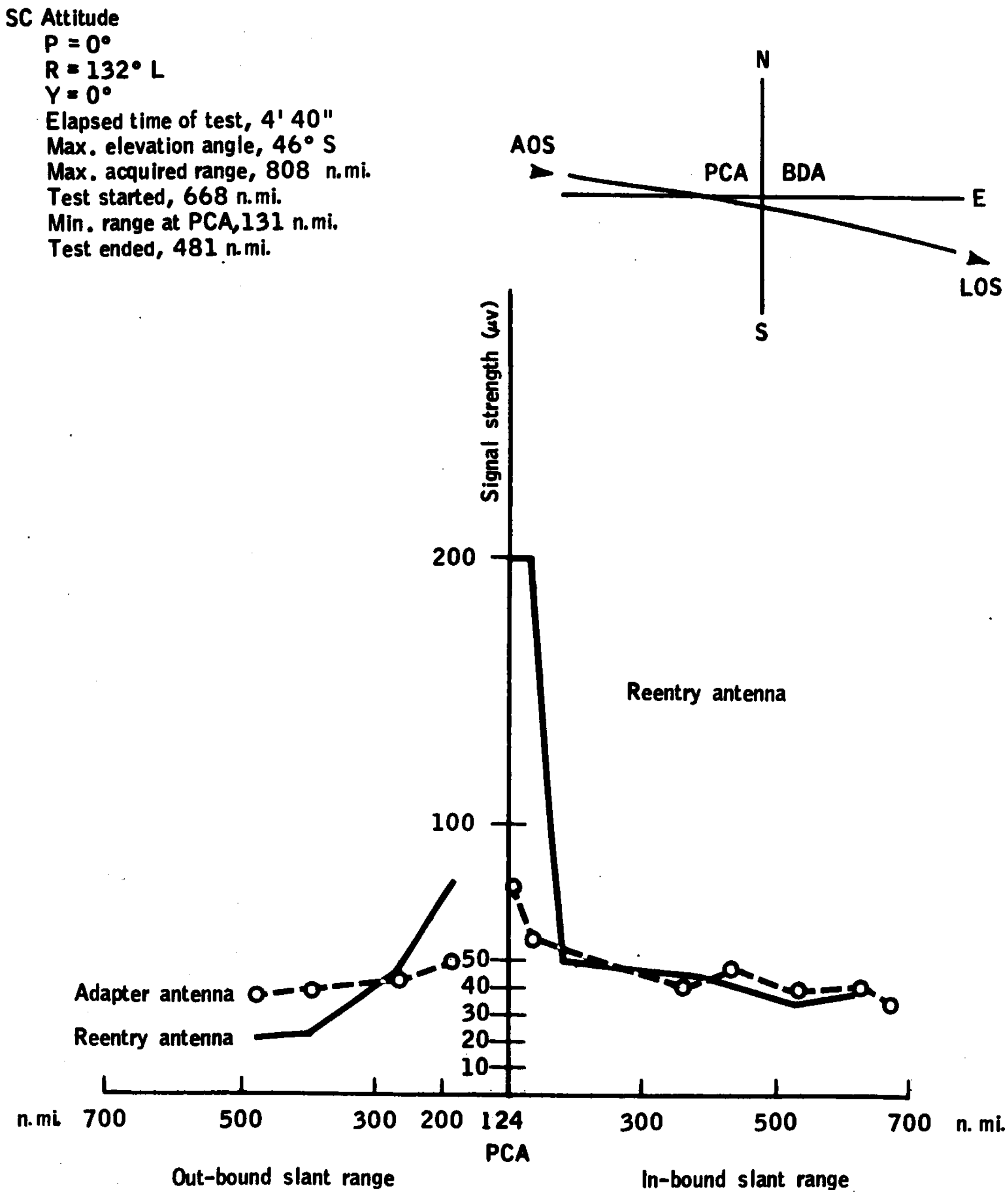



Figure 3-2.- Slant range versus S/G signal strength, UHF voice test no. 2, rev. 32.

NASA-S-65-11669A

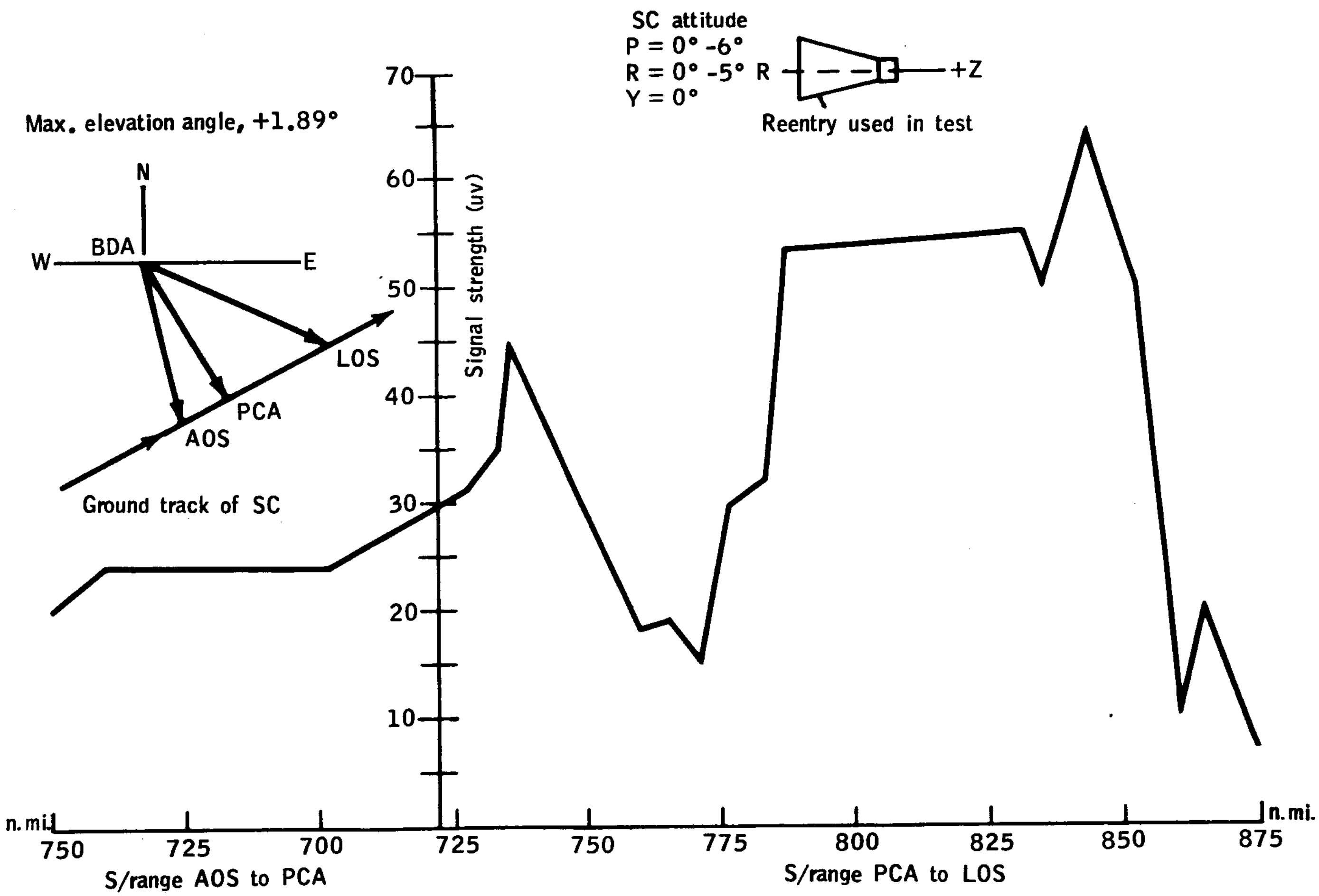



Figure 3-3.- Slant range versus S/G signal strength, UHF voice test no. 3, rev. 14.

NASA-S-65-11668A

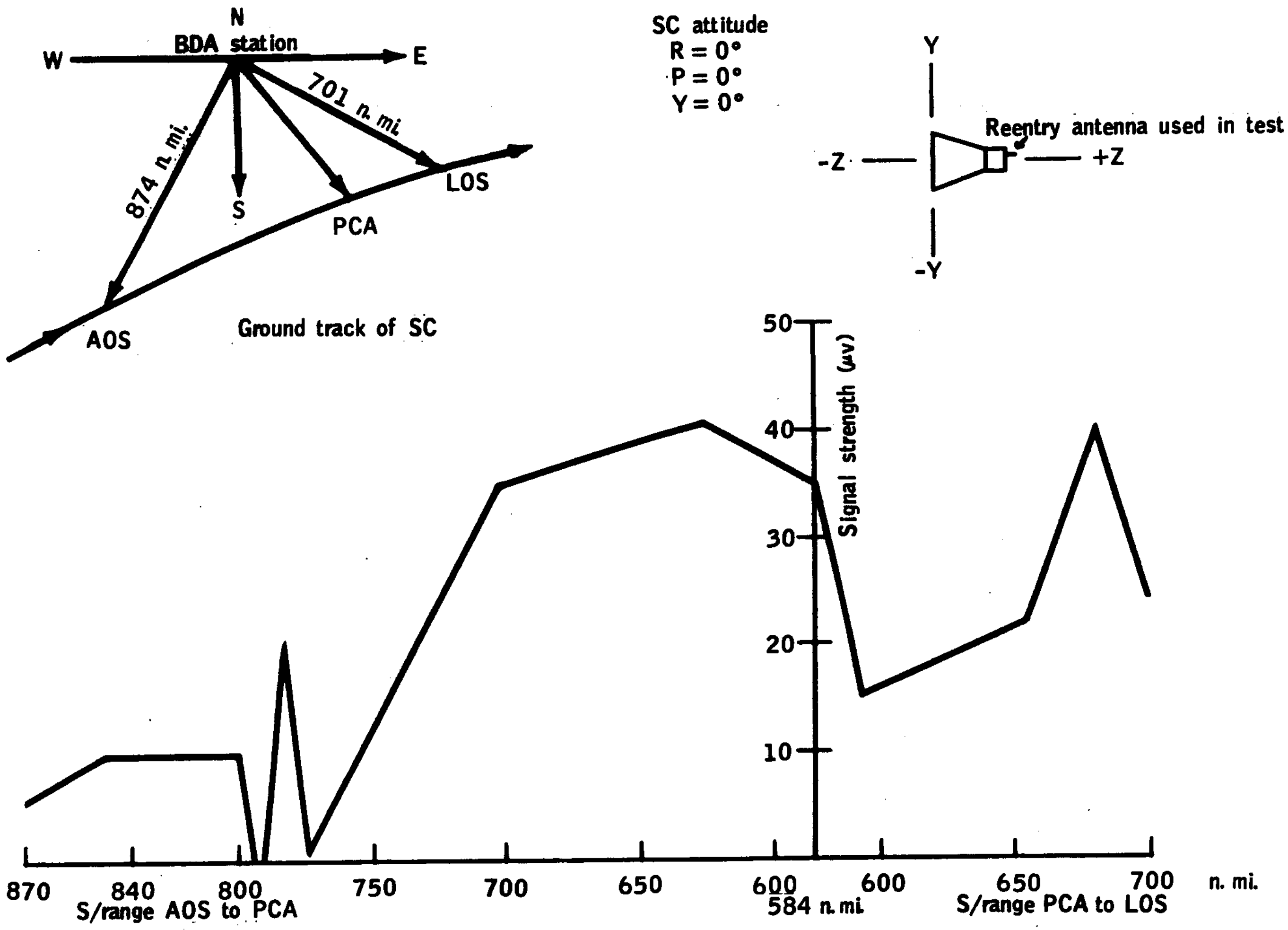



Figure 3-4.- Slant range versus S/G signal strength, UHF voice test no. 4, rev. 29.

NASA-S-65-11672A

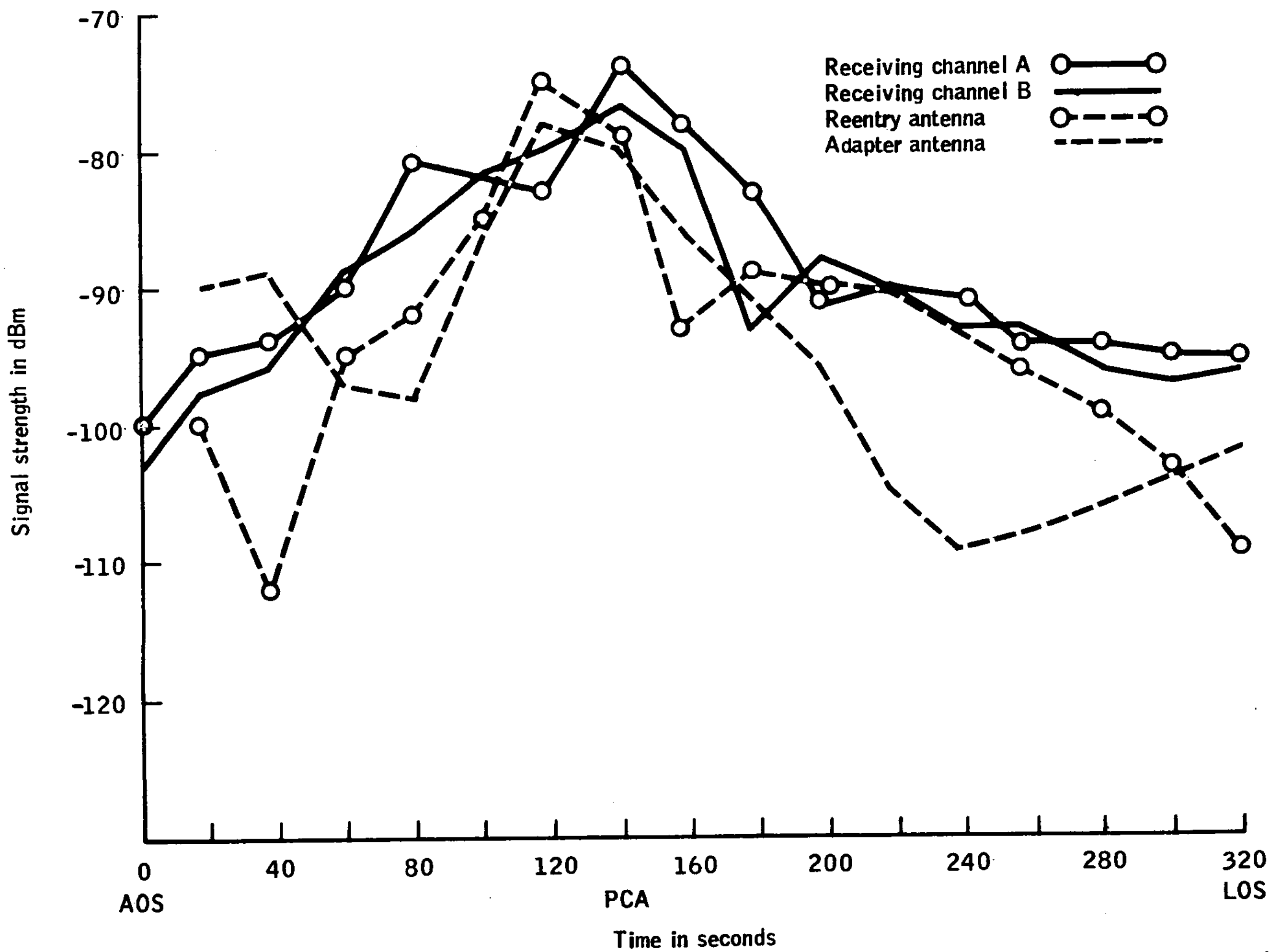



Figure 3-5. - RT telemetry signal strength versus time (at input to receiving channels 1A and 1B) test no. 1, rev. 31.

NASA-S-65-11670A

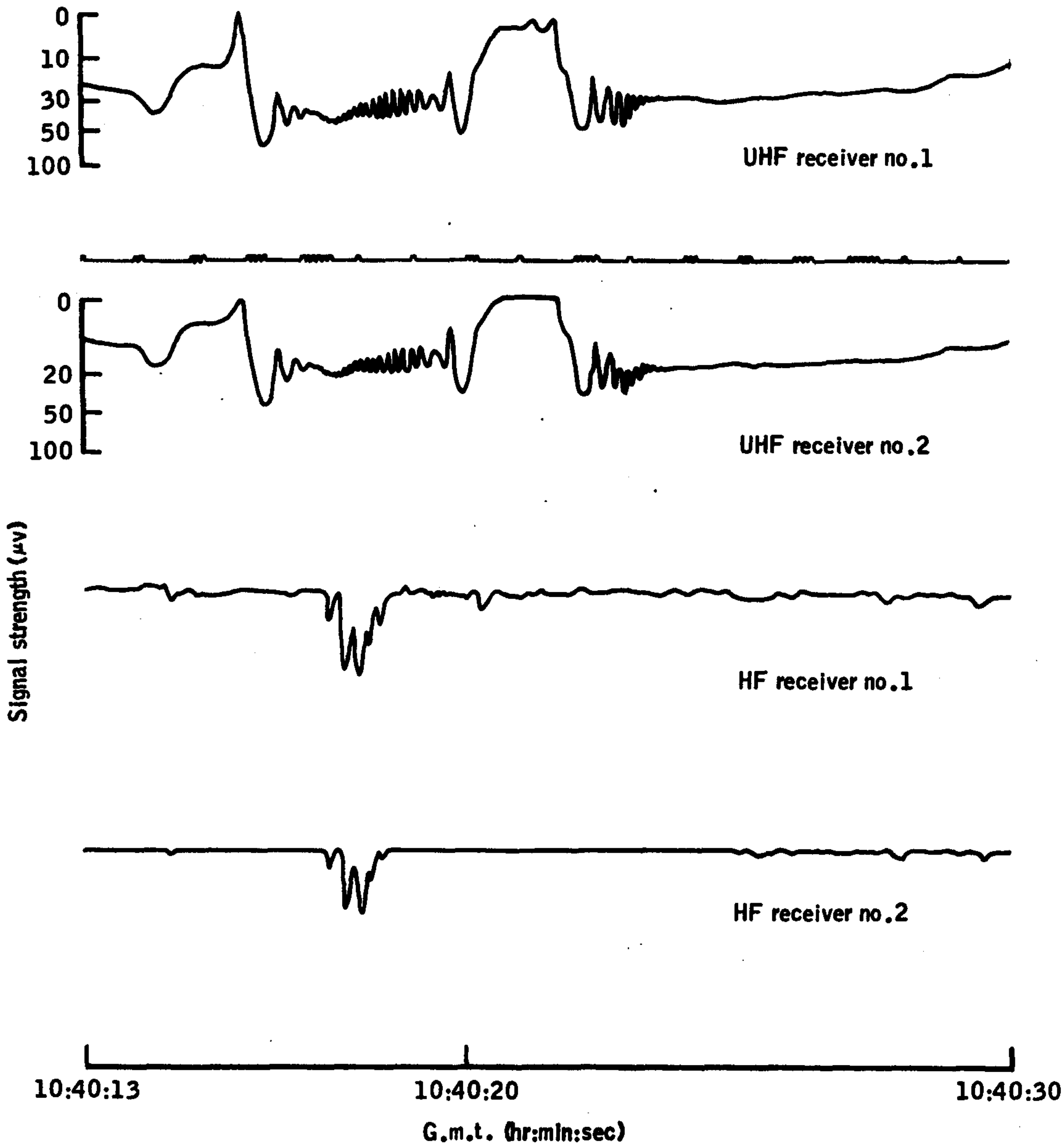



Figure 3-6.- Signal strength versus time interference on UHF voice frequency, test no. 4, rev. 29.

NASA-S-65-11666A

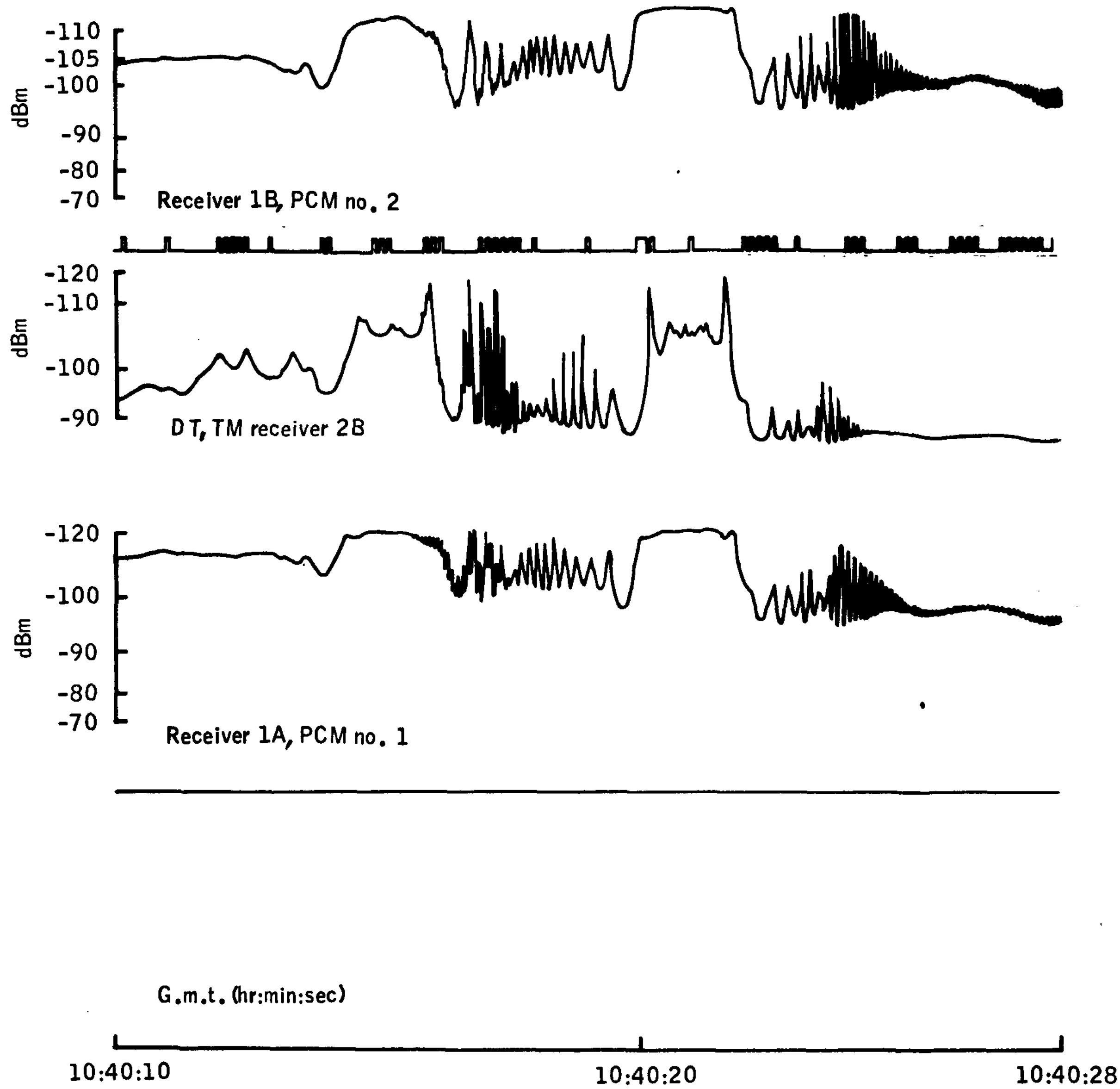



Figure 3-7.- Loss of signal on RT telemetry, test no. 4, rev. 29.

NASA-S-65-11665A

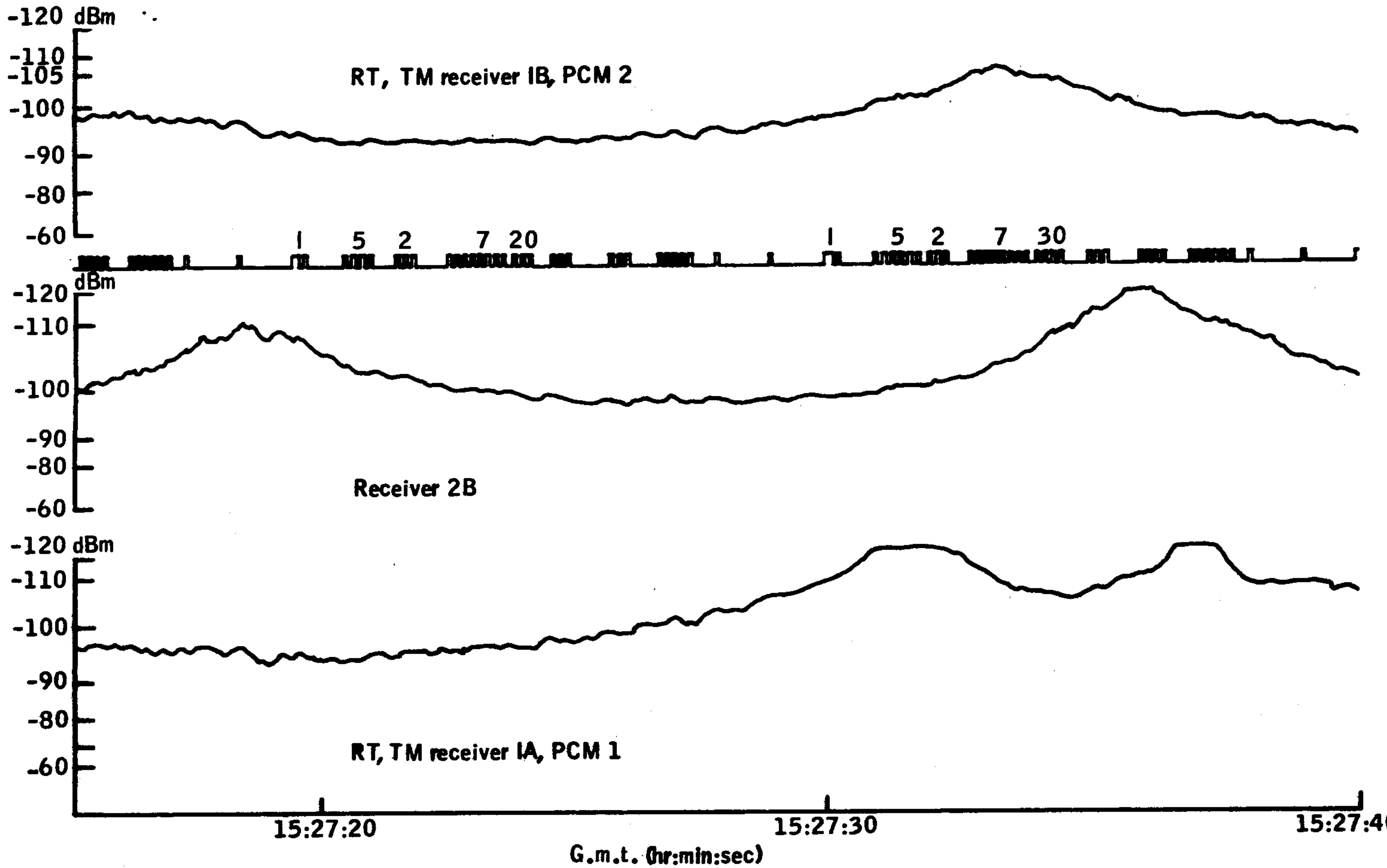



Figure 3-8.- Multipathing effects on signal strength at RT telemetry (freq. 230.4 Mc/sec), UHF S/G test no. 2, rev. 32.

## 4.0 DATA OBTAINED DURING TEST NOS. 1 THROUGH 4

For each of the tests, the following data were obtained:

(a) From Sanborn recordings made during each test, the signal strengths (in microvolts ($\mu V$) at the input of the ground UHF voice receiver no. 2 and at the input of the real-time receiver, and made at 20-second intervals during test nos. 1 through 4) are summarized in tables 3-I through 3-IV, respectively.

(b) The slant range, the elevation, and the azimuth angles of the spacecraft relative to the ground station antenna, were obtained from the tracking data recorded for each of the 20-second intervals referred to in (a) above, and entered in tables 3-I through 3-IV.

(c) Pitch, roll, and yaw of the spacecraft corresponding to the same 20-second intervals, were obtained from the real-time telemetry data, also entered in tables 3-I through 3-IV.

(d) The slant range and angular data of the ground antenna, together with the spacecraft attitude data, were used to calculate the "look" angle of the ground antenna in terms of the spacecraft antenna pattern, coordinate system ($\phi,\theta$). These data are entered also in tables 3-I through 3-IV for each of the four tests. The antenna gain was obtained from these antenna patterns and used this angular ($\phi,\theta$) data; this too is entered in tables 3-I through 3-IV. The trace showing that part of the spacecraft presented to the ground antenna is plotted on the antenna patterns (figs. 2-3 through 2-7) for each of these four tests.

(e) The quality of the UHF voice and of the telemetry data received at the ground station was observed and recorded.

the telemetry, partly because of the smaller circuit margin; but primarily due to the nulls being much deeper at the telemetry frequency (230.4 mcs) than at the UHF voice frequency (296.8 mcs). As illustrated in figure 3-8, multipathing can result in 25 dB nulls at the RT telemetry frequency. Moreover, separating the ground receiving antennas by 182 feet (as at the Bermuda Tracking Station) is not the solution. The resultant field intensity is a function of frequency and difference in path length between the direct and reflected rays; it can be shown that a difference in height of the ground antennas would be more effective in compensating for the difference in path length of the direct and reflected rays.

Many of the unexplained failures in both the UHF voice communication and the telemetry were due to reasons other than a lack of signal strength. For example, as shown in figures 3-6 and 3-7, many failures can be attributed either to improper use of equipment or to sources of manmade interference arising in the immediate vicinity of the tracking station (i.e., low-flying aircraft or surface vessels near the ground antenna).

UHF voice transmissions were not made from the ground during the tests. Consequently, the results cover only the S/G link. A quality analysis of the G/S circuit indicates that the margin is approximately +5 dB less than that of the S/G link, due to the dual-reception system and to the higher sensitivity of the ground receivers.

## 6.0 RECOMMENDATIONS

During the tests, the null areas due to multipathing effects were approximately 15 dBm less at the standby telemetry frequency (259.7 Mc/sec) than at the real-time telemetry frequency (230.4 Mc/sec). It is recommended, therefore, that the real-time telemetry transmitter be used as the backup and the standby transmitter be used to send the real-time data.

The calibrations shown on the signal strength charts for all network stations vary from -120 to -60 dBm at the telemetry frequencies and vary from 0 to 500 μV at the UHF and HF voice frequencies for a full scale deflection of 1.5 inches. Consequently, differences in signal level of less than 5 to 10 dBm are practically impossible to resolve. For a more accurate system evaluation, as that conducted on the Gemini V mission, signal differences of less than 5 dBm (i.e., 3 or even 2 dBm) must be resolved. Therefore, it is further recommended that future calibrations for all network stations vary from -120 to -85 dBm at the telemetry frequencies and vary from 0 to 80 μV at the UHF and HF voice frequencies for a full scale deflection.